Supplementary Information: Anisotropic softening of magnetic excitations in lightly electron doped Sr_2IrO_4

X. Liu,[1,2,3,*] M. P. M. Dean,[3] Z. Y. Meng,[1] M. H. Upton,[4] T. Qi,[5] T. Gog,[4] Y. Cao,[3] J. Q. Lin,[1] D. Meyers,[3] H. Ding,[1,2] G. Cao,[5] and J. P. Hill[3]

[1]*Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China*
[2]*Collaborative Innovation Center of Quantum Matter, Beijing, China*
[3]*Condensed Matter Physics and Materials Science Department, Brookhaven National Laboratory, Upton, New York 11973, USA*
[4]*Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[5]*Center for Advanced Materials, Department of Physics and Astronomy, University of Kentucky, Lexington, Kentucky 40506, USA*

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Sample characterization

The single crystals used in our resonant inelastic X-ray scattering experiments were synthesized using a self-flux technique [1]. In Fig .1, the field-cooled magnetization and resistivity of the electron doped $(Sr_{1-x}La_x)_2IrO_4$ with $x = 0.03$ are shown. Due to the rotation of the IrO_6 octahedra, $(Sr_{1-x}La_x)_2IrO_4$ crystallizes in a reduced tetragonal structure (space group $I4_1/acd$). Thus the crystal a axis is along the (1,1) direction in the notation used in the main text.

The temperature dependence of the magnetization shows that $(Sr_{1-x}La_x)_2IrO_4$ is still magnetically ordered with $x = 0.03$, with a large suppression of its spin susceptibility compared with the undoped compound [1, 2]. The vertical dashed lines indicate the temperature window of its magnetic ordering transition. The take-off temperature is about 218K, which is moderately suppressed from ∼240K for the undoped compound. Above ∼80K, the resistivity along both a and c directions show weak metallic behavior, followed by a strong upturn as the temperature is further lowered. In the temperature window for the magnetic transition, the resistivity along the a direction shows a curvature change, which might be an indication of the coupling of the doped electrons and the magnetism in this system.

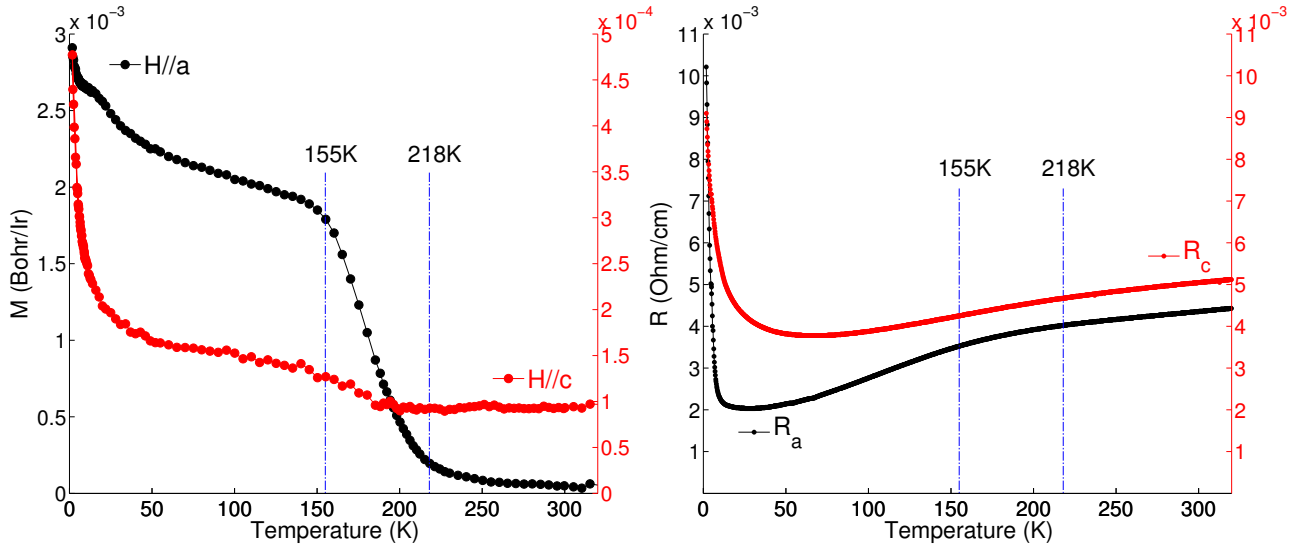

FIG. 1: The field-cooled magnetization with applied field $\mu_0 H = 0.1T$, and the resistivity for the a and c axises for 3% doped $(Sr_{1-x}La_x)_2IrO_4$. The vertical dashed lines indicate the temperature window for the magnetic transition. The curves for a and c directions are presented in black and red respectively.

RIXS measurements on the undoped sample

The RIXS spectra at several $\boldsymbol{Q}$ points near $(\pi/2, \pi/2)$ and $(\pi, 0)$ were collected on our undoped Sr_2IrO_4 sample. The experimental setup was identical to that employed in the measurements on the doped sample, except that the scattered X-ray photons were collected at around 85° instead of 90°. Moving the detector away from 90° helped to enhance the elastic scattering signal, which allows accurate determination of the zero energy transfer.

In Fig .2, the results for the $(\pi, 0)$, $(\pi/2, \pi/2)$ and $(\pi/5, \pi/5)$ points are shown. For the $(\pi/2, \pi/2)$ and $(\pi/5, \pi/5)$ points, the full-width-half-maximum (FWHM) for the elastic peaks was fixed to be 37 meV (the experimental resolution) during the fitting. For $\boldsymbol{Q}$= $(\pi, 0)$, this constrain needs to be relaxed to obtain good quality fit. As a result, the fitted elastic peak was slightly broadened with the FWHM to be 40 meV. Relative to the elastic line center, the magnon energies for $(\pi, 0)$, $(\pi/2, \pi/2)$ and $(\pi/5, \pi/5)$ from our fitting are $197.0(\pm 2.4)$, $105.0(\pm 1.0)$ and $83.7(\pm 1.0)$ meV respectively.

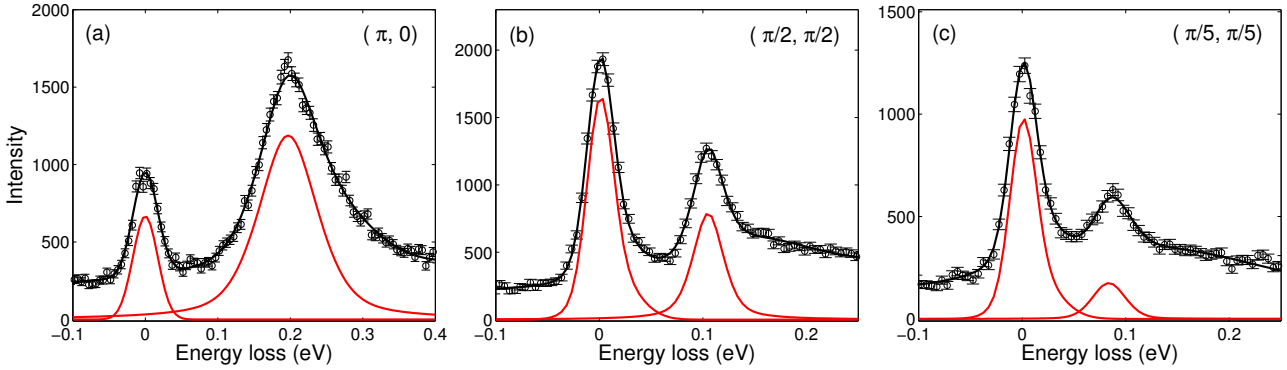

FIG. 2: RIXS energy loss spectra recorded at different $\boldsymbol{Q}$ points. The solid lines through experimental data points are the overall fitting results. The individual peaks are the fitted elastic and magnon scattering respectively. The intensity of the experimental data is shifted by a constant for better view.

The determined magnon energies for our undoped sample are compared with those reported in Ref.[3] in Fig.2 in the main text. The two sets of data show good agreement.

* Electronic address: xliu@iphy.ac.cn

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